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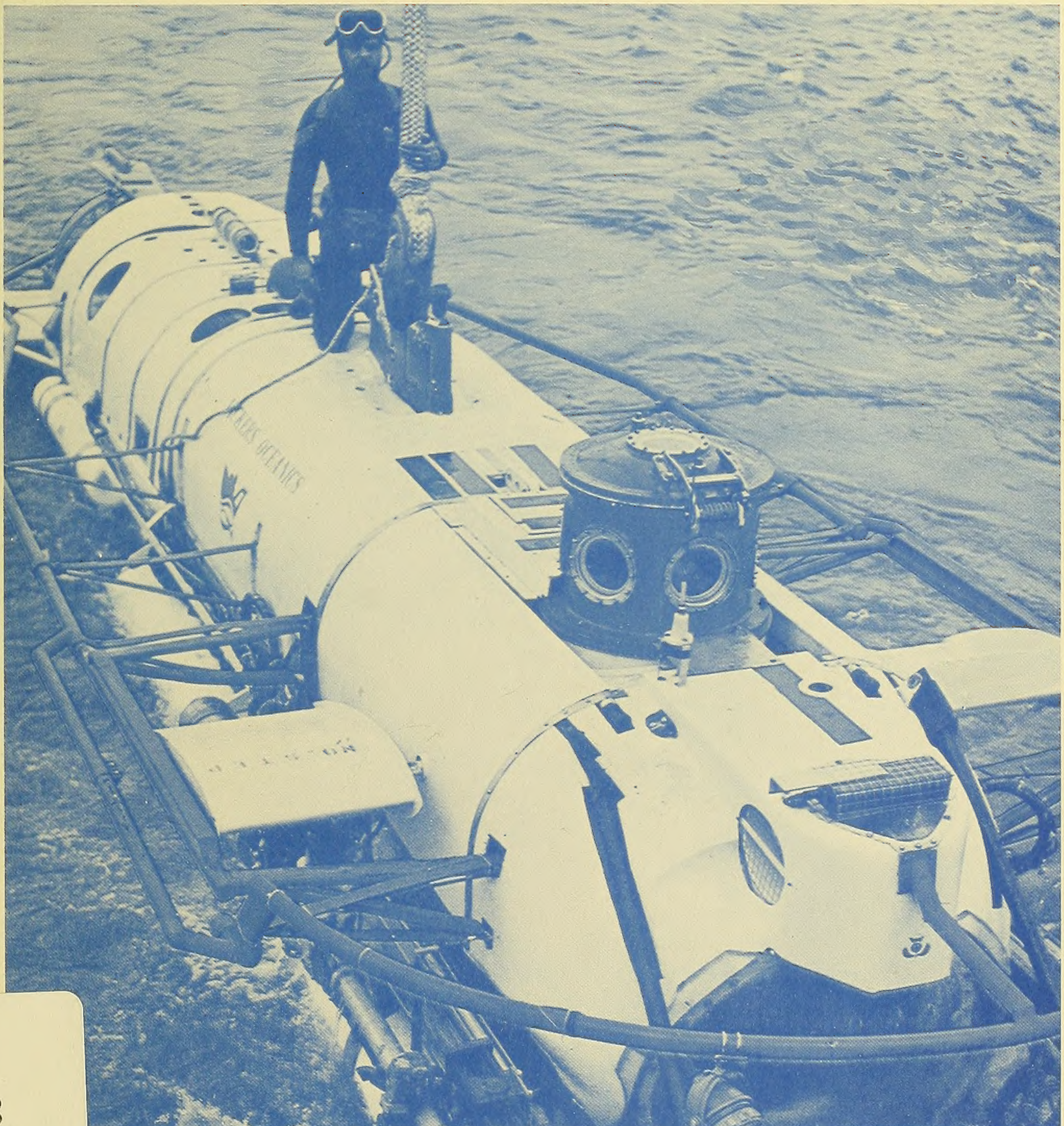
International Status and Utilization of Undersea Vehicles 1976

U.S. DEPARTMENT OF COMMERCE   National Oceanic and Atmospheric Administration



International Status and Utilization of Undersea Vehicles 1976

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INTERNATIONAL STATUS AND UTILIZATION OF UNDERSEA VEHICLES

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ABSTRACT

There are about 100 manned vehicles and 55 unmanned vehicles around the world that are ready for operational use or are under construction. This represents an increase of over 30 percent in one year. New systems are going deeper and providing increased payload capability. Depending on mission requirements, there will always be need for manned or unmanned systems. According to statistics, the U.S. is the leading builder and owner of submersibles followed by France and the Soviet Union.

The highest concentration of vehicles is in support of the offshore oil industry, especially in the North Sea. Following this activity, vehicles are mainly used for inspection, cable laying, salvage, coral harvesting, geology, fisheries, and environmental missions.

Over the last seven years, there have been seven serious accidents reported taking the lives of seven persons. Most of the new vehicles are classified by one of six classification societies. There is a need for international standardization on certain items pertaining to improved safety, especially during emergencies, search and rescue.

The major trends in vehicle design pertain to designing completely integrated vehicle systems, which, in addition to the vehicle, includes support ship, handling gear for launch and retrieval, and logistic support. The major problem is still the launch and retrieval of vehicles, especially in heavy seas.

INTRODUCTION

Over the last decade, the undersea vehicle has evolved from a demonstration of technological capability and scientific curiosity into a very useful means for conducting a variety of undersea work tasks and research missions commensurate with national needs.

Unlike the early systems, the new undersea vehicles are economically designed and built to reliably fulfill specific mission requirements. This approach is necessary to maintain an edge in cost-effective comparisons with other means.

The undersea vehicle transports men and equipment to the work or mission site and serves as an underwater platform for observation, sampling, measurement, and performing various work tasks. Now that undersea vehicles have proven to be a valuable undersea tool, they provide another optional means for satisfying a given set of mission requirements. There are 155 undersea vehicles: 100 manned and 55 unmanned that are listed by country and characterized in tables 1 and 2.

UNDERSEA VEHICLE STATISTICS

Statistics on 155 manned and unmanned undersea vehicles on a world-wide basis are given in Table 3. Of these, there are 100 manned vehicles of which 86 are operational or available and ready for use, and 14 that are still under construction with most expected to be completed before the end of 1976. There are 55 unmanned vehicles of which there are 49 operational or available and ready for use, and 5 that are still under construction.

It is estimated that about 5 percent of the systems deemed operational may be considered marginal relative to their level of readiness because of the additional time that would be required for mobilization, crew training and preparedness. Excluded from this review are wet submersibles operated by divers and those designed for operation in depths less than 600 feet (183 meters). Also excluded from this survey are proposed vehicle designs which may or may not be constructed. However, some of the unique designs are reviewed herein. The total of 155 compares to 103 reported(1) one year ago. However, when taking into account those vehicles inadvertently overlooked in the first world-wide survey, there is about a 32 percent increase in both categories; i.e., manned and unmanned vehicles.

The average characteristics of the world's undersea vehicles are given in Table 3. In averaging the figures, it was necessary to exclude 3 or 4 systems such as the large bathyscaphes to avoid skewing the statistics of the more typical systems.

Because of the continuous trend to go deeper the average depth capability of the world's manned submersibles has increased from 2,250 feet reported one year ago to 2,450 feet, about a 10 percent increase.

The average weight of manned vehicles has increased from 19,000 lbs. a year ago to 24,000 lbs now, about a 26 percent increase. This is due to several factors: going deeper, increasing payload and new systems with diver lockout capability.

There are now 15 vehicles with diver lockout capability, about 15 percent of the manned vehicles.

The average payload capability was calculated to be 1,300 lbs. for manned vehicles and a very low average value for the listed unmanned systems, because most of the unmanned systems are instrumented for a specific mission, and do not provide additional payload space.

In comparing several manned and unmanned systems with given payload capability, there is about a 6 to 1 ratio of depth capability versus weight in favor of unmanned vehicle systems over manned systems. This is mainly due to the fact that the manned system includes a crew which in turn requires habitable space in a pressure hull, life support, and extra power, all of which adds weight and requires compensating buoyancy, and even more power to propel the larger wetted surface system. However, if the given mission requires the man in the system for greater observation capability, better mission control and adaptability, or for diver lockout operations, than the foregoing comparison applies only to certain types of missions.

For the manned vehicles, the average crew size was 3 and the average life support was calculated to be about 120 man-hours or 40 hours per man. This figure is considered low and many believe that 72 hours per man should be the minimum requirements for safety in the event of disablement and need to await search and rescue. However, in some missions that require working in rougher waters, further offshore and at greater depths, provisions should include additional emergency life support capability.

Depending on the mission requirements, there is need for both manned and unmanned systems, and I believe this option will always exist. There are many missions involving hazardous operations; e.g., under the ice packs, areas with potential entanglement problems or operating near radioactive or other hazardous materials, and missions involving long duration area search may better be performed by unmanned, tethered systems.

Though support ships are required with both manned and unmanned systems, each has peculiar requirements. Launch and retrieval of vehicles is still a problem. In addition to cable handling and winching, the unmanned system often requires that the support ship have special maneuvering and station keeping characteristics to tend the tethered vehicle. The manned system requires a heavier duty crane and handling system. For any mission, selection of manned or unmanned systems depends on the outcome of trade-off analysis primarily assessing operating effectiveness in meeting a given set of mission requirements versus cost.

As the state-of-the-art in undersea technology advances in navigation and guidance, remote viewing and search capability, and remote manipulative devices, there will be an increasing trend toward the use of unmanned, tethered vehicles. And, as technology advances in cybernetics, adaptive computer techniques, signal processing, and data storage and transmittal techniques, unmanned, untethered robot vehicles will also increase in utilization. Table 3 also shows ownership of vehicles by country with the United States leading with 64 vehicles followed by France with 26 and Soviet Union with 19. Fifty percent of the vehicles listed in Table 1 were built in the United States.

MANNED VEHICLE DEVELOPMENT

The major undersea vehicle builders in the world are Perry Oceanographics, Inc., Riviera Beach, Florida; and International Hydrodynamics Company (HYCO) Ltd., North Vancouver, British Columbia, Canada. Perry's most recent unique development is the PC-16 vehicle designed for 3,000 foot operation using three interconnecting spheres and providing one-atmosphere transfer capabilities. Construction of two new vehicles, of the PC-18 class, have also been started. The Perry built PC-1202, now owned and operated by InterSub, is illustrated in Figure 1.

HYCO has a unique system under development called TAURUS that will be capable of operation to 2000 feet with a two ton payload capability and diver lockout at lesser depths. HYCO's AQUARIUS I operated by Hyco Subsea is illustrated in Figure 2.

France

COMEX, Marseille, France, has developed a new series of observation and work vehicles called MOANA. The first in the series, MOANA I is illustrated in Figure 3. Another unique development by COMEX is the GLOBULE vehicle illustrated in Figure 4. It is a lightweight two-man subsea helicopter with 360 degrees visibility designed especially for survey and inspection tasks down to 200 meters (660 feet). The GLOBULE is capable of being piloted to the ocean bottom where it positions itself on the platform of a tractor driven cable burying machine and secures itself by four clamping magnets. In this mode, the GLOBULE pilot takes over the control of the machine which can bury a 3-inch cable about 3 feet deep. A pressurized water jet is used to make the trench.

Soviet Union

The Soviet Union now has 12 manned vehicles and 7 unmanned vehicles, about double what was reported in the International Survey[1] made a little more than one year ago. One of their latest submersibles, ARGUS, is illustrated in Figure 5 operating near Gelendzhik on the Black Sea. An interesting new vehicle, the amphibious undersea research vehicle TRITON, is reported to be under development at the Giprorybflat Institute, which designs many Soviet vehicles. The TRITON is primarily intended for construction and support activities in the continental shelf zone and as a true amphibian, it will be able to navigate underwater, on the surface of the water, and on land. Except for TINRO I, which is no longer operational, none of the Soviet vehicles have incorporated diver lockout capabilities.

Germany

In West Germany, the leading submersible builders are Bruker-Physik in Karlsruhe and Ingenieurkontor Lubeck (IKL). Bruker-Physik has built three submersibles in their Mermaid series Figure 6 and IKL has built 2 submersibles in their TOURS series. Last year, IKL directed by Professor U. Gabler prepared several advanced designs for surface independent, self-supporting, compact submarine type systems TOURS 430, TOURS 170, and Deep Subsea Working Systems, DSWS 300 and DSWS 600. The TOURS 430, illustrated in Figure 7, is a submarine configuration 42.5 meters long with a submerged displacement of 830 metric tons and a depth capability of 500 meters. It is equipped with a deep diving system for locking out 4 divers, and a drilling device that can be used for bottom sampling and bore testing on the sea bed to a drilling depth of 200 meters. This type of system configuration is also suitable for use as a mobile underwater laboratory.

Sweden

In Sweden, the rescue vehicle, URF, is under development at Kockums for the Royal Swedish Navy. This 50 ton vehicle is capable of handling a crew of 3 plus 2 divers and a 4,400 lb. payload to depths of 1,500 feet.

Kockums has designed a unique Submarine Support Vessel (SSV)[2] to transport, launch and retrieve a civilian version of the URF. The SSV carries the vehicle in an enclosed compartment forward of the coning tower on the top of the pressure hull. The SSV displaces 1,600 tons and is 65 meters long and capable of operating to 400 feet. The SSV enables submerged launch and retrieval of the URF type vehicle; thus achieving an independent, all weather operating capability avoiding the air sea interface problems.

Kockums has also prepared designs for two unique submarine type systems aimed at the offshore industry for full autonomous operation without a support ship. One is a 170 ton submarine for inspection missions with an endurance capability of 10 days. The other is a 400 ton submarine, 36 meters long with diver lockout capability and mission endurance of 3 weeks or more, and an operating depth capability to 300 meters

UNMANNED VEHICLE DEVELOPMENT

United States

The USA owns and operates over 60 percent of the world's unmanned undersea vehicles; the major developer of unmanned vehicle systems is the U.S. Naval Undersea Center, San Diego, California. Their latest development is the Remote Unmanned Work System (RUWS), Figure 8, capable of operating at depths of 20,000 feet.

HYDRO Tech Systems Incorporated, Houston, Texas, is constructing two major unique unmanned tethered systems, Work Vehicle (WV), Figure 9, and Vertical Transport Vehicle (VTV), primarily for use in remotely controlled pipeline repair work to 4,000 feet with an intermediate capability to operate at 1,800 feet. The characteristics of the 50 ton WV and 60 ton VTV systems are given in Table 2.

Hydro Products, San Diego, California, produces a remote controlled vehicle, RCV-125, for subsea inspection of well heads, pipelines, cables and other structures. Ametek-Straza, El Cajon, California, has developed two unmanned systems—Submersible Craft Assisting Repair and Burial (SCARAB) for AT&T, which can be used for locating the cable by detecting its magnetic properties, uncovering and repairing the cable, and burying the cable. Several new unmanned tethered vehicles such as DEEP DRONE, RECON II, and the Cable Operated Recovery Device (CORD) have been developed mainly for search and recovery.

Soviet Union

The Soviet Union has developed at least seven unmanned systems as listed in Table 2. One Soviet article[3] claims that more than 20 varieties of underwater, remotely controlled vehicles are being used by scientists. Most of these are operated by remote control via a tether because of the poor reliability of wireless control; however, efforts are underway to provide pre-programmed, automatic, robot control without a tether.

The Soviets have developed a system which simulates the presence of a real operator underwater. A moving control panel seat is used to accurately duplicate the movements of the robot. The seated operator senses the movement of the robot via his vestibular mechanism and can rapidly evaluate and intervene with the dynamic situation. Robot development with multi-sensor perception and pre-programmed computer technology is being pursued[3].

Robot Vehicles

Out of the 55 unmanned vehicles reported in Table 2, only 5 are identified as untethered robots. The U.S. has developed 4 robot vehicles—UARS, SPURV, SEA DRONE I and the MIT Robot; the Soviet Union is currently developing one robot vehicle—GIDROPLAN. An untethered robot vehicle has the advantage of not requiring a long unwieldy tether and a surface support vessel with special station keeping characteristics. However, it does require a more sophisticated and costly multi-sensor instrumentation and control system integrated into a multi-channel signal processing and

pre-programmed computer system. High energy density power systems and redundant and emergency modes of operation are required to provide reliable, long endurance operation and safe retrieval of the free swimming robot after mission completion or early termination.

ATMOSPHERIC DIVING SUIT (ADS)

A submersible with arms and legs might be an appropriate description for a diving suit called ADS, or originally JIM, developed for DHB Construction Ltd., U.S., Figure 10. It allows a man to work effectively at atmospheric pressure in water depths ranging to 1,300 feet. It carries its own self-contained life support system and does not require an umbilical coupling. The advantages of the suit are that the divers do not require decompression and the units require relatively little auxiliary equipment and deck space. On deck, the unit weighs 1,000 lbs. and remains in place while the diver enters the suit and the head section is attached. A small crane is needed to launch the diver and he can function with or without a tether. Also, there are no communication problems like those experienced with helium gas for deep diving. The author believes that as the design evolves and improves, there is much potential for a system of this type, especially as divers advance to deeper depths.

VEHICLE OPERATION AND SAFETY

Operation and Handling

Effective, safe operations are the prime objectives of any vehicle operator. One of the major considerations in this area is vehicle handling in launch and retrieval. Therefore, the vehicle operator is concerned with having a compatible, integrated system which includes the vehicle, handling system, and support ship. This is important if a high annual utilization rate is desired, including operation in rough seas and occasionally poor weather conditions.

In the U.S., the leading vehicle operator is the U.S. Navy's Submarine Development Group One, San Diego. In commercial work, the most active operators are General Oceanographics, Inc., San Diego; and International Underwater Contractors, Inc., New York. In scientific work, the most active are the Woods Hole Oceanographic Institution's ALVIN operations (see Table 4), and the Harbor Branch Foundation.

Outside of the U.S., the most active vehicle operators are Vickers Oceanics, Ltd.; Barrow-in-Furness, England; InterSub, Marseille, France; COMEX, Marseille, France, and HYCO Subsea Ltd., Vancouver, Canada. A sampling of the extent of their operational activity is given in Table 5.

The greatest concentration of vehicle activity is in the North Sea where there are about 15 in operation. The world's most active commercial operator, Vickers Oceanics, Ltd., has gained much operational experience in the North Sea, and is mainly involved in cable burial and pipeline survey. Figure 11 illustrates a PISCES submersible being deployed via their proven method of launch and retrieval.

They are capable of vehicle launch and retrieval up to sea state 6. The handling system consists of an "A" frame with a sheave for the lifting line extending over the stern of the support ship, and a smaller inverted "A" frame hanging down from the main frame to prevent athwartship motion when the vehicle is hoisted. A hydraulic arm attaches to the bow of the vehicle to prevent fore-aft swinging motion. An important feature of this system is a small, high speed motor which can overrun the main lifting motors whenever the tension in the line goes to some preselected low value. The retrieval procedure follows: The diver attaches the shackle and line; the vehicle is towed toward the ship; the ship begins lifting the vehicle at about the time the wave starts to lift the vehicle; as the wave lifts the vehicle the tension in the line drops; the high speed motor reels in the line at high speed, up to 600 feet per minute if necessary, to maintain the minimum tension on the line; and, as the wave passes and the tension increases, the main winch continues at its normal hoisting speed. This effective approach uses the sea-induced motion rather than trying to cope with it, gradually transferring the lifting action from sea-dominant motion to ship-dominant motion.[4]

InterSub is another very active operator in the North Sea. InterSub's, Perry-built PC 1202, is illustrated in Figure 12 as a cut-away drawing to show its inner layout plan. Figure 13 shows their proven method of stern launch and retrieval, using a rugged "A" frame arrangement.

The handling system for MOANA, COMEX's vehicle, is a special crane arrangement, illustrated in Figure 14. HYCO Subsea's vehicle handling system, using a rugged "A" frame arrangement is illustrated in Figure 15. HYCO also uses a 97-foot self-powered barge with a floodable stern ramp as a relatively stable platform to launch and retrieve their PISCES vehicles. HYCO claims the deepest dive for commercial work, using the PISCES V at 4800 feet off Sable Island, near Nova Scotia during the fall of 1974, in support of laying a Canadian trans-Atlantic telephone cable.

In the United States, the Johnson-Sea-Link vehicle has a simple, effective handling system illustrated in Figure 16, and the retrieval procedure is as follows: The diver attaches the line by simply inserting a novel drop-lock into the lifting fixture; the vehicle is towed toward the ship; as the line is winched into the crane, the quick acting, articulated crane raises the vehicle at about the same time a wave lifts the vehicle; the vehicle is hoisted out of the water and placed on the afterdeck. A strong-back type antisway bar is used to prevent the hoisted vehicle from swaying.

The ALVIN system continues to effectively use their proven elevator launch and retrieval arrangement used on the catamaran support ship, LULU, for over 600 dives. Another novel handling system still being used after 500 dives, is Deepwater Exploration Ltd's, Launch-Retrieval Transport (LRT), Figure 17, shown serving as a platform for the STAR II. This approach involves transporting STAR II on-board the LRT to the site; ballasting the system for complete submergence, and then, at a predetermined depth, divers release the vehicle from the LRT for a smooth take-off. Underwater launch and retrieval minimize the problems of the air-sea interface. However, operations in heavy seas with an LRT-type platform that must be towed to the site, creates other problems. A submerged launch and retrieval system, using a submarine as a support ship, is being developed by Sweden's Kockums, to handle their URF-type vehicle.

The major vehicle operating problem is still its handling during launch and retrieval in heavy seas. However, several good approaches have been noted herein.

Classification of Vehicles and Safety

An important consideration in vehicle development, ownership, and operation is having the vehicle system designed, built and tested in accordance with a classification code. This provides an added degree of confidence regarding performance and personnel safety; and insurance companies often consider this as one of the criteria in establishing underwriting coverage. There are nine classification organizations worldwide:

* American Bureau of Shipping
Bureau Veritas
* Det Norske Veritas
* Germanischer Lloyd
* Lloyd's Register of Shipping
Nippon Kaiji Kyokai
Polish Register of Shipping
Registro Italiano Navale
USSR Register of Shipping

* Vehicle classification data were tabulated for comparison in last year's report.(1)

This tabulation revealed slight variations between each agency, and a number of items are listed as guidelines and not requirements. The classification process in most agencies relies on design review and observation of tests by an inspector. As stated previously,(1) it is the author's opinion that some standardization between the classification agencies would be desirable, especially in some basic areas pertaining to emergencies, search and rescue. For example in the event of disablement on the bottom, it would be desirable to provide the crew with a minimum number of hours of life-support per man, e.g., 72 hours, under normal operating conditions; and some greater number based on distance offshore, depth, expected sea state, and weather conditions. In order to communicate and signal location during disablement, it is desirable to standardize on frequencies for underwater telephones and emergency acoustic beacons. Although ones own support ship can probably make contact, other rescue forces brought

to the scene may not be so equipped. Once located, the next step is to recover the submersible; and it would be very desirable for each submersible to have a standard hooking arrangement located at an established lift point.

A report entitled, "Self-Help Rescue Capability for Submersibles"(6) provides the following list of items considered mandatory as self-help rescue features for undersea vehicles:

- Acoustic beacon on a standard distress frequency (37 kHz).
- External standard lift points.
- Acoustic communications on a standard underwater telephone (8-11 kHz).
- Minimum operator qualifications.
- Filing of dive plan with a potential rescue unit.
- Passenger predive briefing.

The Marine Technology Society's Undersea Vehicles Safety Standards Subcommittee(7) is preparing a plan to formulate submersible safety standards. The objectives are to improve safety in vehicle operation, and to improve rescue response capabilities.

The plan involves establishing three working groups, one each on:

- Personnel qualifications and training
- Operational plans and procedures.
- Emergency equipment.

It also involves getting good representation on an international basis, especially from the major submersible operators, designers, and builders. The results of this effort will be documented in an MTS book "Recommended Safety Standards for Undersea Vehicles," to be published at the end of 1977. This will be a third in the series of books prepared by this Subcommittee; the other two are entitled "Safety and Operational Guidelines for Undersea Vehicles."(8)

Manned Submersible Accidents

There have been seven major submersible accidents within the last seven years, which were reported to have occurred during underwater operations, taking the lives of seven persons. Last year's report(1) provides a table listing six of these accidents, along with data pertaining to their location and recovery.

In September 1975, there was a fatal accident reported involving the STAR II submersible and its Launch-Retrieval Transport (LRT), Figure 17. It was reported that two of the divers, supporting the submerged launching of the STAR II, lost their lives trying to free the STAR II while the LRT continued to sink uncontrollably, and the safe diver depths for air breathing were exceeded. The third diver barely made it back to the surface.

A good reference source, pertaining to submersible safety through accident analysis, is Appendix IV of Book II, "Safety and Operational Guidelines for Undersea Vehicles."(8) A book entitled "Manned Submersibles"(9) contains a chapter "Emergency Devices and Procedures," and another chapter "Emergency Incidents and the Potential for Rescue."

VEHICLE UTILIZATION

Within the last year, there has been over a 30 percent increase worldwide in available undersea vehicles, primarily in support of offshore development activities, especially the oil industry. The summation of data on manned vehicles listed in Figures 18, 19, and Tables 4 and 5, reveals that inspection, mainly of pipelines and cables, was the leading mission category worldwide, followed by cable burial. A listing of the leading mission activities sampled on a worldwide, dive-day basis, in descending order are:

- Inspection (pipeline, cable, etc.)-- 50 percent
- Cable burial -- 18 percent
- Engineering, salvage, etc. -- 12 percent

The following categories, representing the balance of about 20 percent of the missions, are placed in descending order, though there are only small differences between them:

- Coral harvesting
- Geological
- Biological, Fisheries
- Pollution, ocean dumping

There are no data in this report on unmanned vehicle activities, although unmanned vehicles have been busy, but on the average, not as busy as manned systems. An example of one noteworthy mission, carried out for several weeks in the summers of 1974 and 1975, was conducted by the U.S. Environmental Protection Agency, using the CURV III unmanned vehicle to survey, photograph, and sample around a radioactive dumpsite near the Farralon Islands, off the coast of California. Data concerning the integrity of the radioactive waste containers and the fate of any leaking pollutants is of world-wide interest in establishing a policy for future dumping.

United States

Although many new undersea vehicles were built in the United States by Perry, the vehicles available for use in the U. S. has changed negligibly -- from 29 to 30. The utilization of underwater vehicles in the U.S. over the last three fiscal years, is illustrated in Figure 18. The number of total dive-days in Fiscal Year 1975 diminished by about 15 percent, from Fiscal Year 1974, and this is primarily attributed to a reduction of U.S.-operated submersibles in the North Sea, from three to one, despite the fact that about 13 out of 18 (including those under construction) were built in the U.S. by Perry, but are owned by European operators. Inspection, mainly of pipelines and cables, was the leading U.S. mission, and this correlates with world-wide activities. Coral harvesting, represented only by the STAR II's activities off the east coast of Oahu, in the Hawaiian Islands, has been increasing steadily over the last three years, in quest of jewelry-quality, pink and black coral at 1000-foot depths.

Fisheries and biology missions have exhibited slight decreases each year, whereas geology missions increased somewhat. Most of the biology efforts are attributed to the ALVIN operations in studying the deep-ocean food chain, and also the deep-benthic fish and other organisms. Other missions have included studies on: the underutilized species of crab at the 2000 to 3000-foot depths; the habitation and migration of deep water lobster and shrimp; and on the deployment and effectiveness of line arrays of lobster traps. In pollution studies, sewer outfalls were monitored, and ocean dumpsites were inspected in the New York Bight region.

As noted in Table 4,[5] the ALVIN has made over 600 dives, of which about 22 percent involved test and training, and the balance of the missions were mainly oriented to geology and biology. It is interesting to note that the ALVIN has spent an equivalent total of almost 100 continuous days under the sea, and has developed a steadily increasing average time for dives, which is now 4.3 hours.

This is the second of a three-year arrangement whereby the Navy, NSF, and NOAA are sharing the cost and use of the deep-diving ALVIN. Two-thirds funding by Navy-NSF enable ALVIN utilization as a national facility under the University National Oceanographic Laboratory System (UNOLS). NOAA is using their allocated time mainly for ongoing fisheries and environmental research programs.

Federal use of American Bureau of Shipping (ABS)-classed civilian-operated manned vehicles was less than 10 percent of the total available submersible time during the last three years.

The U.S. Navy's undersea vehicle utilization in FY 1975 involved about 190 dive-days, mainly for deep undersea inspection missions, training and testing, as illustrated in Figure 19. The PC-14C-2, owned by the Army's Ballistic Missile Command, has the special mission of recovering missiles and associated debris entering the spashdown area of the Kwajalein Missile Range.

World-Wide Utilization

Utilization of undersea vehicles, as sampled on a world-wide basis, excluding the U.S., is given in Table 5 for reference. U.S. data were combined with Table 5 data to provide the aforementioned figures on world-wide usage.

Although statistical data are not available it is reported that the Soviet undersea

vehicles are mainly involved in fisheries research. The OSA-3-600, owned and operated by the National Institute of Sea Fisheries and Oceanography, has been used in fisheries research, for example, to hover over a school of fish and transmit data on the extent, location, and speed of movement of the school. It is also capable of taking core samples from the ocean bottom for later analysis by petroleum scientists. The unmanned tethered vehicle, SKORPENA (also operated by this Institute), is reportedly utilized in oceanographic and biological research on illuminescence and bioluminescence. The SEVER 2, operated by the Polar Institute of Fish and Oceanography, is reportedly operating in the North Atlantic, looking for schools of fish, studying the sea bottom, and selecting areas for trawl fishing. In the Black Sea, most of the Soviet activities originate from their base at Gelendzhik. A good reference for information on Soviet undersea vehicle activities is presented in reference (9).

Coral harvesting off Taiwan is conducted using BURKHOLDER I, and red coral harvesting near Corsica is conducted using ANTONIO MAGLIUOLO.

The most active vehicle noted in the survey was the HAKUYO, owned by Japan Ocean Systems, Inc., that reportedly made 624 dives in 45 days.

MISSION APPLICATIONS

The preceding section described many mission applications suitable for undersea vehicle usage, mainly with the offshore industry. Undersea vehicles play an important role in the offshore industry's undersea installation of: offshore structures, sub-sea oil completion systems, pipelines and cables. Vehicles are used for: preinstallation surveys; diver transport and assistance during installation of structures and pipelines; cable burial; post installation inspection; and pipeline and cable repair work. In view of the extensive network of offshore platforms, sub-sea completion systems and pipelines, the security of these facilities will bring on new mission requirements. As the offshore industry goes deeper the need for vehicles becomes even greater. A study(11) by Vickers Oceanics Ltd, indicates that from a cost-effectiveness standpoint, the cross-over point between utilizing a diver with Scuba versus a manned submersible is about 150 meters, based upon environmental conditions. The development of the atmospheric diving suit, which in reality is a manned submersible, may bridge this area. Pipelines are being planned for depths greater than 3000 feet, and there are international rulings that require pipeline installations to be readily repairable. To address this type of need, Hydrotech Systems of Houston, Texas, is developing the 50-ton unmanned tethered WORK VEHICLE, and a 60-ton unmanned tethered VERTICAL TRANSPORT VEHICLE: and the Shell Development Co., Houston, TX, designed a 300-ton Submersible Pipeline Repair System (SPRS), Figure 20.

Coral harvesting is expected to continue and perhaps expand as new areas are found. Geological missions, such as the microscale examination and selective sampling of the deep-ocean rift zone of the Mid-Atlantic Ridge, conducted by France and the U.S. in Project FAMOUS, is another example of effective use of undersea vehicles. Deep-ocean seismic studies of rift and fault areas, and geophysical exploration for oil and gas deposits, are other areas of useful application. Studies of this type under ice are planned by Horton Maritime Exploration Ltd, for utilization of their recently overhauled AUGUSTE PICCARD.

In fisheries application, there is much to be done in management and assessment of stocks. The undersea vehicle was proven useful in getting more selective data on fish stocks for correlation with gross data obtained by trawling. Lobster habitation studies along the northeast seaboard, conducted using vehicles, revealed flat, barren plains that have potential for lobster development, but are void of habitats. Studies of such areas deploying artificial habitats might prove useful. Deployment of lobster at various stages of development, including fry, might give some indication of survival and development in a controlled area, barren, but conducive to lobster development.

Underutilized species of fish and crab at depths in excess of 600 feet might be surveyed and assessed as sources of food or feed stock. Studies of the deep ocean food chain continue and much data are still needed to better understand this process.

In environmental research, vehicles are most useful in surveying and selective sampling

of dumpsites to determine the extent and fate of pollutants and impact on marine life. Undersea vehicles can effectively assist in baseline studies where periodic selective sampling on, near, and below the bottom layers is required over a wide area.

Deep-ocean mining will require the use of manned or unmanned systems for location, survey, and assessment of manganese modules as well as for selective sampling and measurement pertaining to environmental research in baseline-impact studies. With the exception of the two bathyscaphes, the U.S. Trieste II, and France's Archimede, there are no other manned systems capable of participating in deep-ocean mining from 12,000 to 20,000 feet. Plans have been made for modifying the U.S. Navy's Sea Cliff for 20,000 feet. However, there are at least six unmanned systems that are capable of operating at these depths.

Undersea film making on archeological findings, sunken cities, and lakes in Scotland are the mission plans of Margen Internacional, S. A.'s MARGENAUT, refurbished former SUBMANAUT, Figure 21.

DESIGN TRENDS

Undersea vehicles are being utilized more, now that experience has proven their utility and systems are designed in accordance with user requirements. A major trend pertains to designing a completely integrated system, which, in addition to the submersible includes support ship, handling gear for launch and retrieval, and logistic and maintenance support. The objective is to obtain an effective, high utilization rate under varying weather conditions. Equipment for conducting efficient deep-water surveys will require the use of improved navigation and guidance systems at costs affordable by submersible owners. Greater dexterity of manipulators will be needed for manned and unmanned systems to perform intricate operations more quickly. Many new vehicles are being developed with large panoramic plexiglass windows to provide a wider viewing field very effective in survey and inspection missions. Trays of dry batteries mounted in cylindrical pods, external to the pressure hull, with quick access for servicing and replacement and rapid turnaround time, is another notable design trend.

A number of compact, unmanned vehicles have been built for search and rescue of manned vehicles. In those operating areas where other manned vehicles are not close at hand, more unmanned systems are expected to be available for use in such emergencies, to locate and attach a recover line. Harbor Branch Foundation's Sea Guardian System, consisting of support craft and the cable-operated Recovery Device (CORD), is an example of such a system, Figure 22.

Within the last year, a number of designs for small submarine-type systems have emerged to provide fully autonomous, long-duration, capability for missions such as: pipeline and cable inspections; installation and repair; selective drilling; sub-bottom profiling and sampling. These systems also feature diver lock-out capabilities which provide even more operational flexibility. Their general utility, as mobile undersea laboratories in support of commercial diving and scientific research, provides another major application. These systems would not require a surface vessel, and would operate independently for several weeks, with surface cruising ranges on the order of 3000 nautical miles. In view of expanding mission requirements, construction of the first of this class system is expected to start within the next year or so.

CONCLUSIONS

Within the last five years, undersea vehicles have proven to be a significant tool in ocean research and development, and their abundance and utilization is steadily increasing.

The offshore industry is the principal user, and there are many other mission applications that will require more extensive usage. The latest designs feature fully integrated systems (vehicle, ship, handling gear, and logistics and maintenance support) to ensure an effective high utilization rate.

More specificity and standardization is needed by the classification societies in the vital areas pertaining to improved safety, search and rescue. Safety standards in areas of crew qualifications, operating procedures, and emergency equipment, should be developed by the user community to the extent not encumbering innovation in design and effective utilization of vehicles.

ACKNOWLEDGEMENTS

The author would like to thank the many submersible builders, owners, and operators world-wide, who furnished data on the design and utilization of their vehicles; and acknowledge the periodic inputs from Mr. Frank Busby of R. F. Busby Associates. I would also like to thank the NOAA, Manned Undersea Science and Technology staff for preparing the manuscript.

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TABLES

Table 1. Major Characteristics of Manned Undersea Vehicles World-wide

Vehicle	Operator	Depth (ft)	Crew	Length Beam (ft)	Weight (lbs)	Payload (lbs)
AUSTRALIA						
PLATYPUS I c	Univ.of Sydney	1000	2	15,4	4,500	
CANADA						
AQUARIUS I	HYCO Subsea	1100	2	14,6	11,000	880
AQUARIUS II c	HYCO Subsea	1100	2	14,6	11,000	880
AQUARIUS III c	HYCO Subsea	1100	2	14,6	11,000	880
SEA OTTER	Arctic Marine	1100	2	14,5	6,300	550
SDL-1*	Canadian Navy	2000	5	20,10	30,000	2,560
AUG.PICCARD	Horton Maritime	2500	4	94,20	366,000	20,000
PISCES VI	HYCO Subsea	6600	3	19,10	24,400	1,900
PISCES IV	Dept.of Enviro.	6600	3	19,10	24,100	1,500
PISCES V	HYCO Subsea	6600	3	19,10	24,400	1,900
PISCES IX c	HYCO Subsea	6600	3	19,10	24,400	1,900
COLUMBIA						
DOWB	Friendship S.A.	6500	3	17,9	20,000	1,050
FRANCE						
GLOBULE	COMEX	660	2	9,6	5,400	
PC8B	InterSub	800	2	19,6	11,000	500
SHELF DIVER*	DCAN	800	4	23,6	17,000	1,200
PC1201	InterSub	1000	2	22,8	18,000	1,000
PC1202*	InterSub	1000	5	31,8	33,000	1,500
PC1203	COMEX	1000	2	22,8	18,000	1,000
PC1204	InterSub	1000	2	22,8	18,000	1,000
MOANA I	COMEX	1300	3	14,-	20,000	
MOANA II c	COMEX	1300	3	14,-	20,000	
MOANA III c	COMEX	1300	3	14,-	20,000	
MOANA IV c	COMEX	1300	3	14,-	20,000	
MOANA V c	COMEX	1300	3	14,-	20,000	
SP-350	COF	1350	2	9,9	8,400	300
SP 500 (2)	COF	1620	1	10,6	5,300	100
GRIFFON	DCAN	1970	3	24,7	29,400	440
DEEPSTAR 2000	G.O.Int'l	2000		20,7	15,500	1,000
PC 16	InterSub	3000	4	25,8	33,000	600
DEEPSTAR 4000	COMEX	4000	3	18,12	18,000	500
CYANA	CNEXO	9840	3	19,10	17,600	440
ARCHIMEDE	CNEXO	36000	3	69,13	122,000	6,000
GERMANY (FRG)						
MERMAID IV* c		1000	3		28,000	
ITALY						
ANTONIO MAGLIUOLO (TOURS 66)	Sarda Estracione Lavorazione	1000	2	20,10	20,000	880
ANDRY (PC-5C)	SubSea Oil	1200	2	22,4	10,000	750
PC8C	SubSea Oil	1200	2	23,6	12,000	1,100
PHOENIX 66* c	SubSea Oil	1200	7		77,000	
JAPAN						
UZUSHIO	Nippon Kokan	650	2	18,10	10,400	
KUROSHIO	Hokaido Univ	650	2	37,7	25,000	
HAKUYO	Japan Ocean Sys.	985	3	21,5	13,200	330
SHINKAI	Japan Maritime Safety Agency	1970	4	50,28	200,000	4,000
NETHERLANDS						
NEREID 700*	Nereid N.V.	700				
SKADOC 1000*	Skadoc Sub Sys.	1000	3	18,5	6,600	
POLAND						
DELFIN-2*	Geological Inst.	650	2		3,680	
SOVIET UNION						
TRITON c (Amphibious URV)	Giprorybflot Institute					
GVIDON	Research Inst.of Fish.&Oceanog.	820	3	15,8	8,580	
ATLANT II	Atlantic Inst. of Fisheries	1000	2	15,-	6,500	
AQUARIUS	Acad.of Science	1300	3			
PISCES VII	Acad.of Science.	1500	3	19,10	24,000	2,400
TINRO II	Pacific Fish.Lab	1500	2	36,9	80,000	
ARGUS	Acad.of Science	2000	3	-,7	22,400	
OSA-3-600 I	Research Inst.of Fish.&Oceanog.	2000	3			
OSA-3-600 II	Research Inst.of Fish.&Oceanog.	2000	3			
SEVER I	Research Inst.of Fish.&Oceanog.	2000	1			
PISCES XI	Acad.of Science	6600	3	19,10	24,100	1,500
SEVER II	Polar Inst.of Fish.&Oceanog.	6600	4	36,8	65,000	
SWEDEN						
URF c	Royal Swedish Navy	1500	5	45,14	110,000	4,400
TAIWAN						
BURKHOLDER I	Kuofeng Ocean Develop.Corp.	1000	2	20,10	20,000	880
UNITED KINGDOM						
MERMAID III*	P & O Subsea	850	5	21,6	28,000	
VOL-LI* & L2*	Vickers Oceanics	1200	4	32,8	28,000	2,000
PC-9	P & O Subsea	1350	4	26,7	22,500	500
PISCES I	Vickers Oceanics	1500	2	16,11	5,000	1,600
LEO I c	P & O Subsea	2000	3	19,10	26,500	1,800
TAURUS* c	P & O Subsea	2000	4	34,13	53,000	4,000
PISCES II	Vickers Oceanics	2400	3	19,10	24,000	1,900
PISCES VIII	Vickers Oceanics	3000	3	19,10	24,000	1,500
PISCES III	Vickers Oceanics	3000	3	19,10	24,000	1,900
PISCES X	Vickers Oceanics	3000	3	19,10	24,000	1,900
UNITED STATES						
SEA RANGER	Verne Engr.Corp.	600	4	17,8	19,000	2,200
NEMO	SW Research Inst.	600	2	6,6	2,000	850
PC-3B	Int'l U.W.Contr.	600	2	22,4	6,350	1,000
SEA EXPLORER	Sea Line Inc.	600	2	15,5	3,600	300
PRV-2*	Pierce Subs Inc.	600	3	19,8	15,500	1,000
MARGENAUT	Margen Int'l	600	8	44,9	108,000	6,000
NEKTON ALPHA	Gen.Oceanographics	1000	2	15,4	4,500	300
NEKTON BETA	Gen.Oceanographics	1000	2	15,4	4,700	460
NEKTON GAMMA	Gen.Oceanographics	1000	2	15,4	4,700	460
JOHNSON SEA LINK*	Harbor Br.Found.	1000	4	23,8	21,000	1,200
SNOOPER	Undersea Graphics	1000	2	15,4	4,500	200
GUPPY	SunShip&Drydock.	1000	2	11,8	5,000	400
OPSUB	Ocean Systems	1000	2	18,8	10,400	400
SEA RAY	Sub.R & D Corp.	1000	2	20,5	9,000	350
MERMAID II	Int'l U.W.Contr.	1000	2	17,6	14,000	1,000
NEMO I	Seaborne Ventures	1000	3	12,8	20,000	1,200
DIAPHUS	Texas A&M Univ.	1200	2	13,5	10,000	225
PC-14C-2	ArmyMissile Com.	1200	2	13,5	10,000	225
STAR II	Deepwater Explor. Ltd.	1200	2	17,5	10,000	500
PC-17* c	Perry Oceanog.	1500	4	34,8	38,000	500
DEEP VIEW	SW Research Inst.	1500	2	16,6	12,000	500
JOHNSON SEA LINK*	Harbor Br.Found.	2000	4	23,8	21,000	1,200
BEAVER MK IV*	Int'l U.W.Contr.	2700	5	25,8	34,000	2,000
DSRV-1	U.S. Navy	5000	4	50,8	75,000	4,300
DSRV-2	U.S. Navy	5000	4	50,8	75,000	4,300
SEA CLIFF	U.S. Navy	6500	3	26,12	42,000	700
TURTLE	U.S. Navy	6500	3	26,12	42,000	700
DEEP QUEST	Lockheed	8000	4	40,16	115,000	7,000
ALVIN	Woods Hole Oceanog.Inst.	12000	3	23,8	32,000	1,500
TRIESTE II	U.S. Navy	20000	3	78,19	180,000	2,000

c = Construction   * = Diver Lockout

Table 2. Major Characteristics of Unmanned Undersea Vehicles World-wide

Vehicle	Operator	Depth (ft)	Length Beam (in)	Weight (lbs)	Lifting Payload (lbs)
CANADA					
BATFISH	Bedford Inst.	650	52,29	154	0
TROV	Canada Center Inland Waters	1200	66,36	1,130	-
FRANCE					
PAP	Societe ECA	600	106,-	1,760	-
TELENANTE I	Institute Francais Petrol	1000	162,60	2,200	-
TELENANTE II	Institute Francais Petrol	1000	162,60	2,200	-
ERIC	French Navy	3300	180,72	4,410	16,000
TROIKA	DCAN	7220	170,82	2,000	-
JAPAN					
OCEAN SPACE ROBOT	Mitsubishi Ind.	800	180,31	3,530	-
GERMANY (FRG)					
IBAK	IBAK	19700			
MANKA c (Test Model)	GKSS		150,72		
NORWAY					
CABLE CONTROLLED VEHICLE	Royal Norwegian Navy	1800			
SOVIET UNION					
MANTA (2 Units)	Acad.of Science	1000			
GIDROPLAN c	Acad.of Science	1000			
KAYMAN		2000		800	-
SKORPENA	Research Inst. Fish.& Oceanog.	3300	130,60	1,000	-
KRAB-1	Acad.of Science	10000	100,80	1,000	
KRAB-2	Acad.of Science	10000			
UNITED KINGDOM					
TROV-01	Underground Location Services	1200	84,50	2,000	
CONSUB	Inst.of Geology	2000	96,65	1,760	290
SEXTON	MATSU				
CUTLET	Ministry of Defence.				
UNITED STATES					
BUOYANCY TRANSPORT VEH.	USN Civil Eng.Lab.	850	96,72	1,800	1,000
SOLARIS	Naval Torpedo Sta.	1500	-,-	--	
ELEC.SNOOPY	Naval Undersea Ctr.	1500	39,24	150	0
ELECTRIC SNOOPY II	Naval Facilities Engr. Center	1500	45,28	300	0
CORD	Harbor Br.Found.	1500	70,41	770	50
UARS	Univ.of Washington	1500	120,19	900	0
RECON II	Perry Oceanog.	1500	42,36	450	-
SCAT	Naval Undersea Ctr.	2000	72,24	400	80
DEEP DRONE	Ametek Straza	2000		5,000	
RUFAS II	Miss.State Univ.	2400	132,66	1,000	0
CURV II	Naval Undersea Ctr.	2500	180,72	3,450	400
CURV IIB	Naval Torpedo Sta.	2500	180,72	3,000	400
J-STAR	Jacobsen Bros	3000	-,-	--	
SCARAB (2)	A.T.&T. Co.	6000		5,000	
DOWS	Ametek Straza	6000		5,000	
SORD I	Naval Torpedo Sta.	6500	72,48	4,000	
SORD II	Naval Torpedo Sta.	6500	72,48	4,000	
RC-125	HYDRO Products	6560			
CURV III	Naval Undersea Ctr.	7000	180,78	4,500	2,000
RUM/ORB	Scripps Inst. of Oceanog.	8000	150,108	24,000	
NEDAR I	Assoc.Marine Ser.	10000	72,72	2,400	
SEA PROBE	Ocean Search Inc.	10000		400,000	
SPURV	Univ.of Wash.	12000	120,24	1,000	100
TELEPROBE	Naval Oceanog Off.	20000	96,60	3,500	1,600
DEEP TOW	Scripps Inst. of Oceanog.	20000	64,13	324	0
SEA DRONE I	Pre Con, Inc.	20000	210,24	2,800	0
MIZAR FISH	Naval Research Lab.	20000	105,30	1,800	0
RUWS	Naval Undersea Ctr.	20000	123,58	4,300	1,000
NEDAR II	Assoc.Marine Ser.	25000	72,72	1,800	2,000
WORK VEHICLE c	HYDROTECH	4000	50',22'	110,000	40,000
VERTICAL c TRANSPORT VEH.	HYDROTECH	4000	70',22'	130,000	100,000
UDOSS c	Jet Prop. Lab.	20000	118,42	3,000	0
ROBOT VEHICLE	M.I.T.		96,15	250	0

c = Construction

Table 3. Summary Statistics on Undersea Vehicles

Status	Manned	Unmanned
World-wide - operational or ready	86	50
World-wide - under construction	14	5
World-wide - Total	100	55
Average Characteristics		
Design Depth (ft)	2,450	6,000
Weight (lbs)	26,000	2,200
Payload (lbs)	1,300	--
Crew Size	3	--
Life Support (man-hours)	120	--
Ownership by Country		
United States	30	34
France	21	5
Soviet Union	12	7
United Kingdom	11	4
Canada	10	2
Japan	4	1
Italy	4	0
Germany (FRG)	1	2
Netherlands	2	0
Poland	1	0
Australia	1	0
Columbia	1	0
Sweden	1	0
Taiwan	1	0

Table 4. Utilization of the ALVIN Submersible

	Year Totals 74	Year Totals 75	Cumulative Totals to 1 Jan. 76
Total Number of Dives	60	58	604
Total Dives, Test & Training	7	4	136
Total Mission Dives	53	54	468
Mission Categories:			
Orientation	0	0	60
Biology	13	37	122
Geology	32	9	142
Search & Recovery	2	3	45
Equipment Inspection	6	0	28
Navigation Experiments	0	0	24
Other Science & Engineering	0	5	47
Total Time Submerged (hrs)			2,236
Average Time for Dive (hrs)			4.3

Table 5. Utilization of Undersea Vehicles as Sampled on a World-wide Basis Excluding the U.S. (July 1974 through December 1975)

Vehicle	Mission Category	Mission Location	Dives	Dive Days	Average Depth (m) or Range
CANADA					
SDL-1	Test	Nova Scotia	16	15	75
SDL-1	Training	Nova Scotia	68	36	75
SDL-1	Inspection	Nova Scotia	10	10	300
PISCES V	Cable Burial	Nova Scotia	27	20	1450
AQUARIUS I	Survey Oil Barge	Prince Ed. Isl.	6	6	76
AQUARIUS I	Guideline Replace-ment for Well Head	Prince Ed. Isl.	14	15	75
AQUARIUS I	Cable Burial	Block IsL, USA	15	15	75
AQUARIUS I	Cable Inspection	Nova Scotia	6	6	75
FRANCE					
CYANA	Test & Training	Mediterranean	28	28	30-2700
CYANA	Geology - (FAMOUS Proj.)	Azores	15	15	3000
CYANA	Pipeline Insp	Mediterranean	3	1	400
CYANA	Pipeline & Cable Inspection	Sicily	44	36	100-600
PC8B	(Offshore Support	North Sea	400	212	150
PC1201	Activities-Mainly	North Sea	231	90	200
PC1202	Pipeline Survey)	North Sea	79	50	200
JAPAN					
HAKUYO	Pipeline Insp	Aga. Niigata	230	15	30-81
HAKUYO	Fisheries	Shizuoka	204	17	30-200
HAKUYO	Fisheries	Kanagawa	44	1	65
HAKUYO	Biology	Sagami Bay	84	3	115-134
HAKUYO	Equipment Emplace-ment	Wakayama	49	4	147-250
HAKUYO	Cable Inspection	Ibaragi	9	2	83-167
HAKUYO	Salvage	Kagoshima	4	3	125
UNITED KINGDOM					
PISCES I	Navy Missions	W. Scotland	292	312	40-200
PISCES II	Pipeline Work	North Sea	150	151	40-200
PISCES II	Cable Burial	Bay Biscay	26	32	40-200
PISCES III	Pipeline Work	North Sea	30	30	15-120
PISCES III	Cable Burial	Bay Biscay	107	107	15-120
PISCES III	Platform Survey	North Sea	130	128	15-120
PISCES V	Pipeline Work	North Sea	77	77	30-160
PISCES V	Cable Burial	North Sea	59	59	30-160
PISCES VIII	Pipeline Work	North Sea	5	5	30-140
PISCES VIII	Cable Burial	Bay Biscay	46	46	30-140
VOL-L1	Pipeline Work	North Sea	26	26	3-160
VOL-L2	Trials	North Sea	20	20	10-60

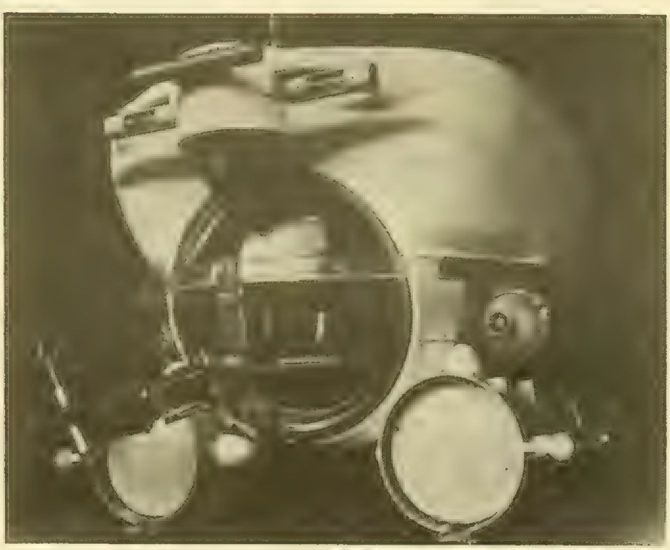

Fig.2. AQUARIUS, Built by International Hydrodynamics Co.,Ltd.,Operated by HYCO Subsea.

FIGURES

Fig.1. PC-1202, Built by Perry Oceanographics Inc.,Owned and Operated by InterSub.

Fig.3. MOANA I Owned and Operated by COMEX

Fig.4. GLOBULE,Owned and Operated by COMEX

Fig.5. ARGUS,Owned by the Soviet Academy of Sciences

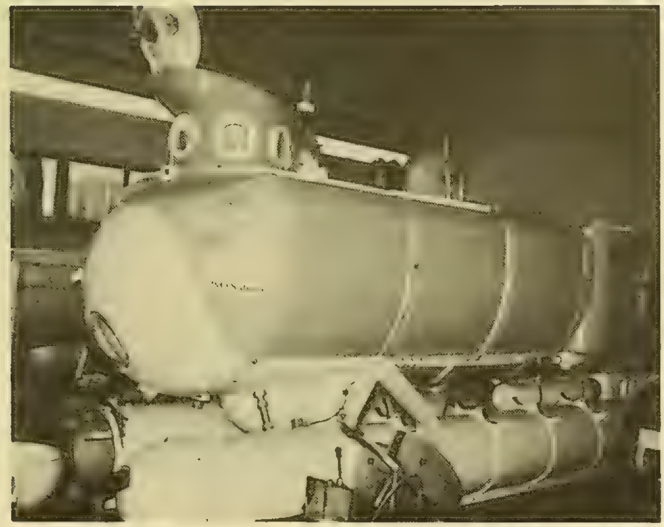

Fig.6. MERMAID III,Built by Bruker-Physik Owned & Operated by P&O Subsea

Fig.7. TOURS 430, Designed by Ingenieurkontor Lübeck

Fig.8. Remote Unmanned Work System (RUWS), Developed by the U.S. Naval Undersea Center

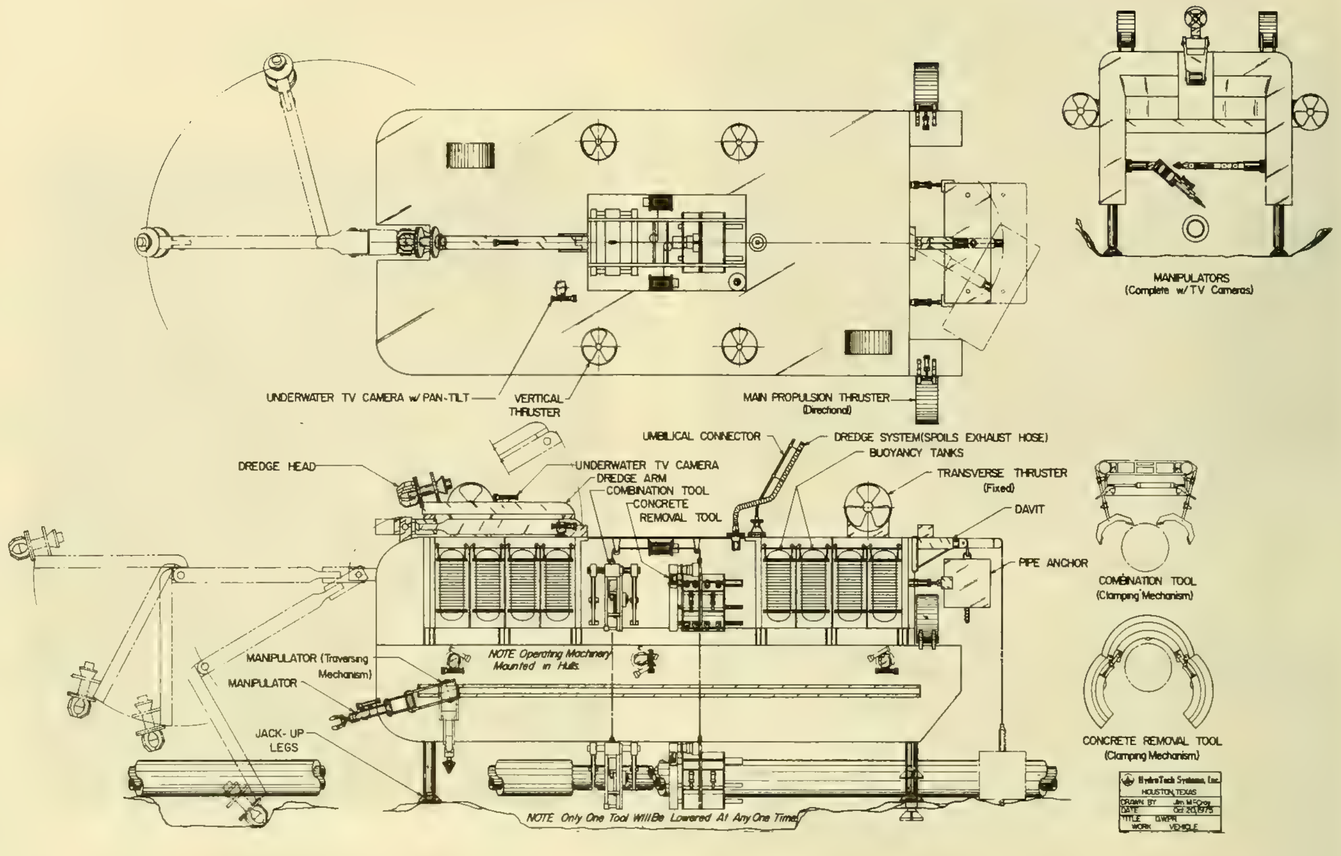

Fig.9. WORK VEHICLE (WV), Designed by HydroTech Systems Inc.

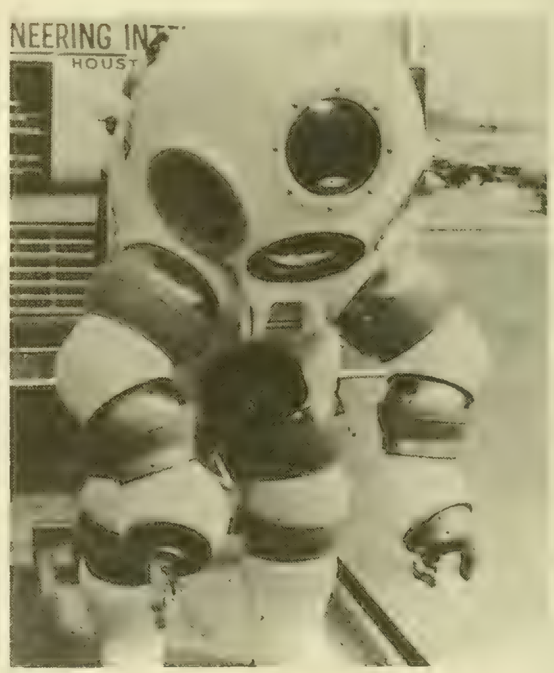

Fig.10. ATMOSPHERIC DIVING SUIT (ADS), Developed for DHB Construction Ltd.

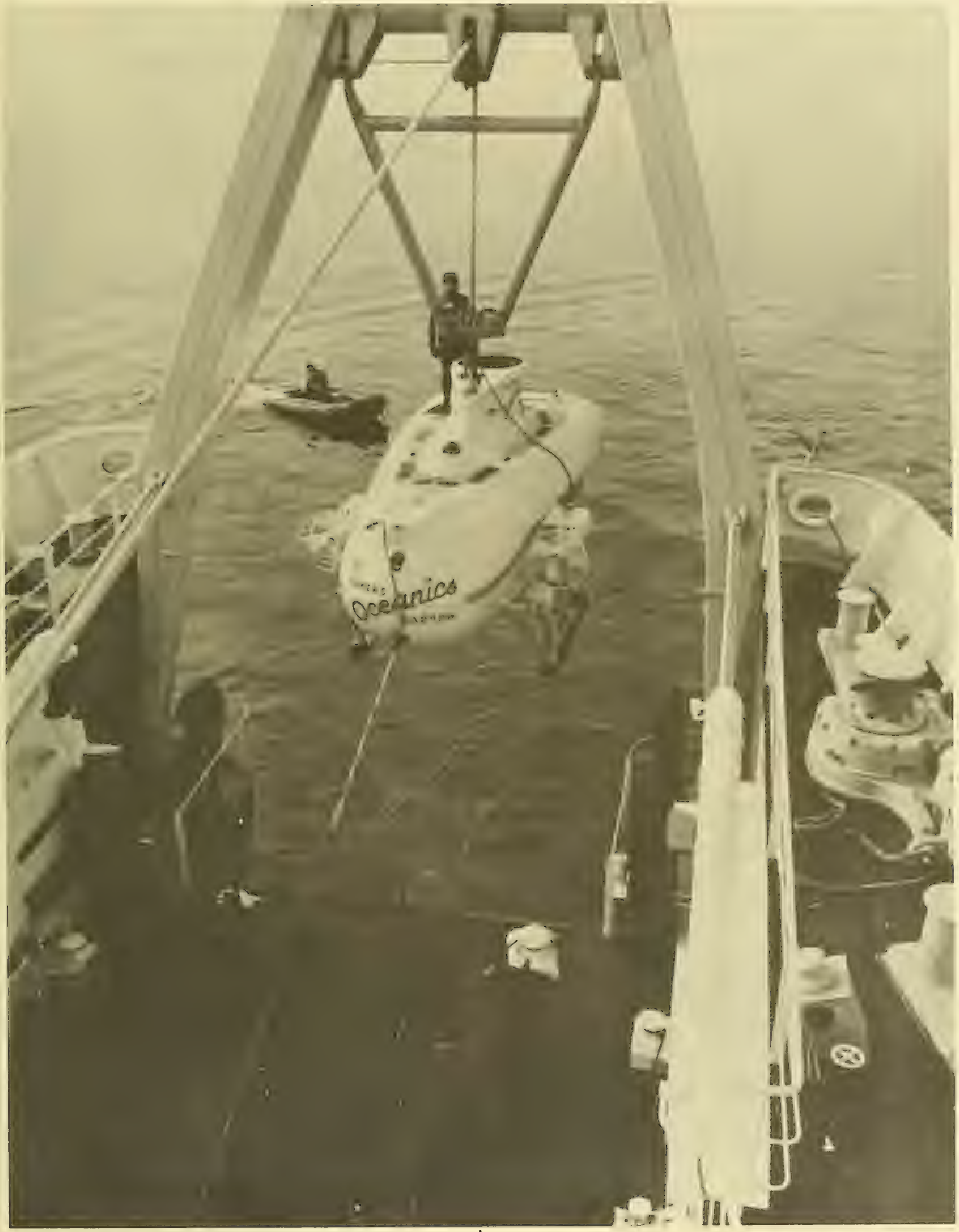

Fig.11. Vickers Oceanics Inc. Ltd.'s Support Ship and A-Frame Crane Handling PISCES III.

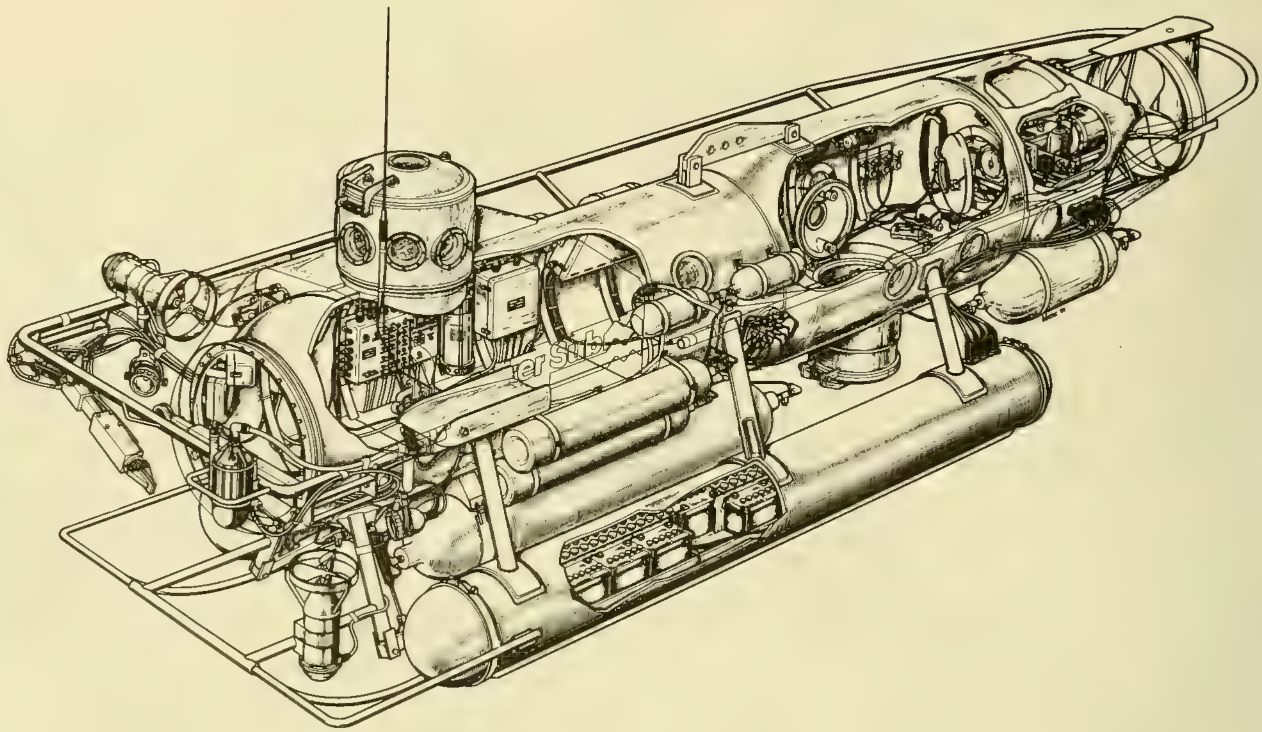

Fig.12. Cut-away Drawing of InterSub's PC-1202, Built by Perry

Fig.14. COMEX'S MOANA I and Handling System

Fig.13. InterSub's Support Ship and A-Frame Crane Handling PC-1201

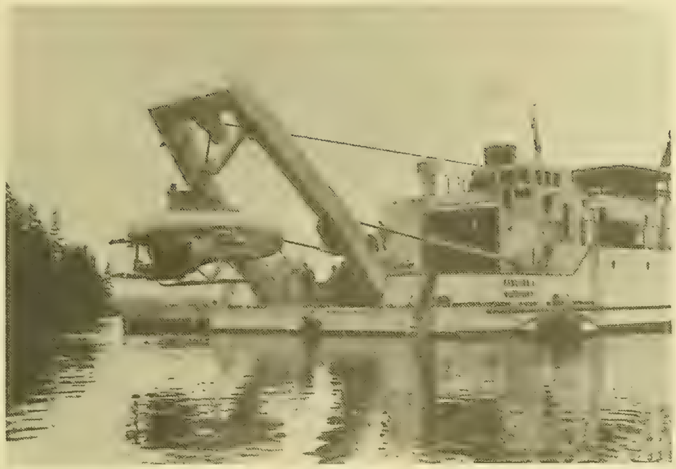

Fig.15. HYCO Subsea's Support Ship and A-Frame Crane Handling PISCES IV

Fig.16. Harbor Branch Foundation's RV JOHNSON with Articulated Crane Handling JOHNSON SEA LINK

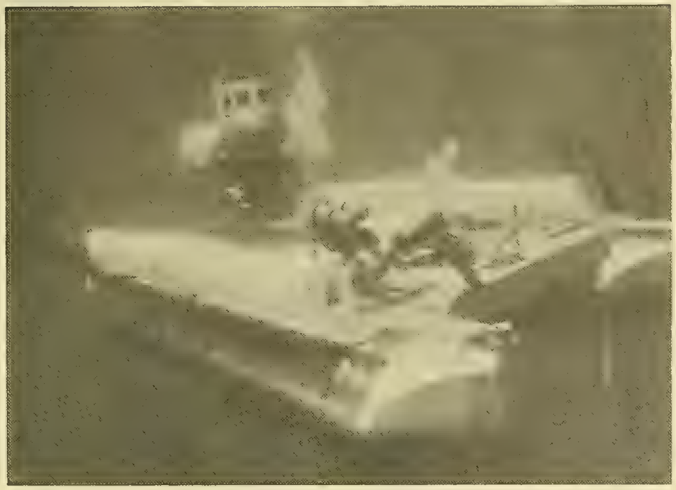

Fig.17. Deepwater Exploration Ltd's STAR II and the LRT

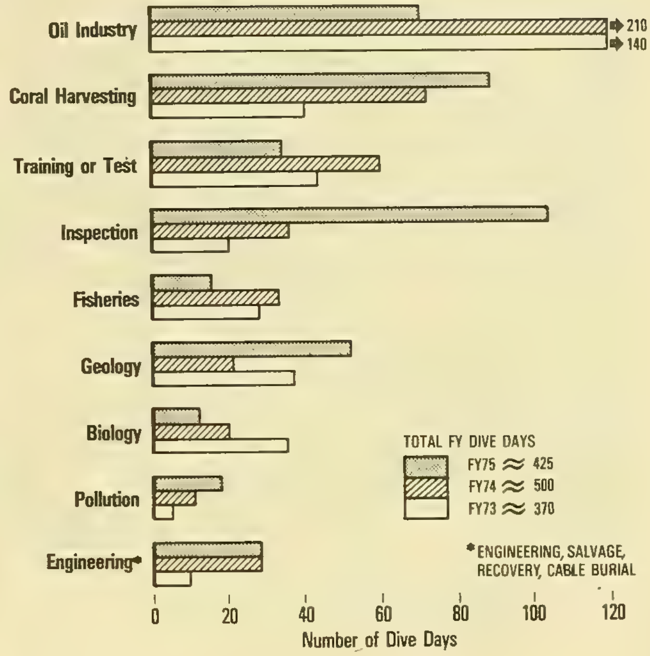

Fig.18. Civilian Manned Undersea Vehicle Utilization in the U.S. during Fiscal Years 73, 74 and 75

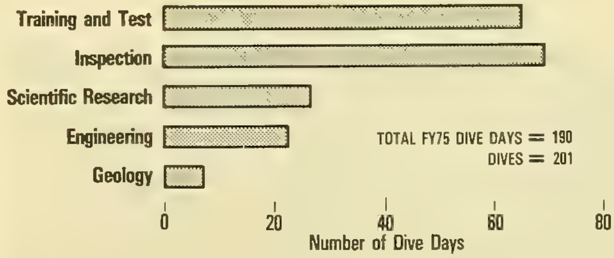

Fig.19. U.S. Navy's Manned Undersea Vehicle Utilization in Fiscal Year 1975

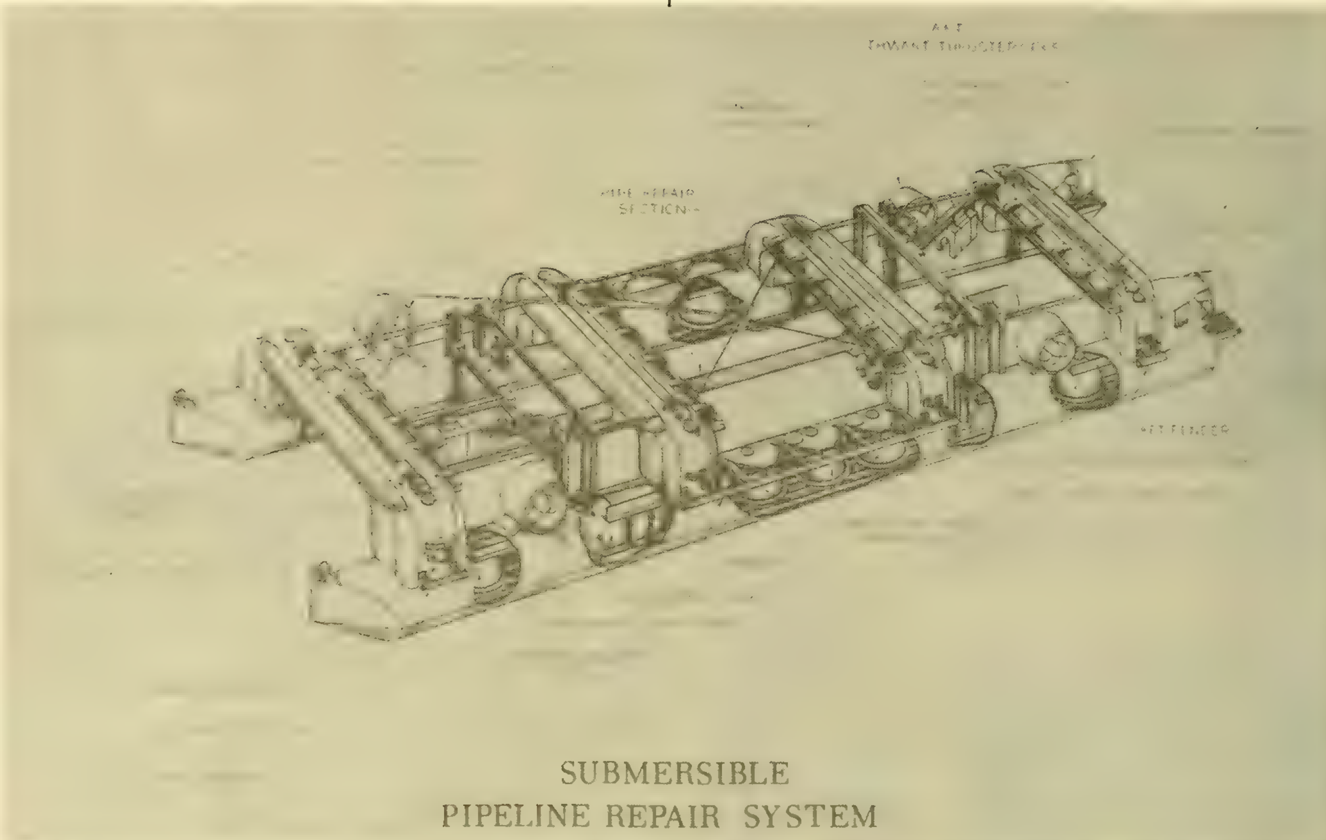

Fig.20. Shell Development Co.'s Design for an Unmanned Submersible Pipeline Repair System

Depth: 3,000 ft; Weight: 300 tons; Length: 153 ft; Beam: 43 ft; Payload Lift: 100,000 lbs

Fig.21. MARGENAUT (formerly SUBMANAUT), Owned and Operated by Margen Internacional, S.A.

Fig.22. Harbor Branch Foundation's SEA GUARDIAN SYSTEM

APPENDIX A*

U.S. Owned and Civilian Operated Undersea Vehicles that are Navy Certified or ABS Classed.

Out of the 30 U.S. manned undersea vehicles, 25 are civilian operated and of these the 14 listed below are or are expected to be ABS Classed or Navy Certified:

	Depth (ft)
PRV-2	600
NEKTON BETA	1,000
NEKTON GAMMA	1,000
JOHNSON SEA LINK I	1,000
JOHNSON SEA LINK II	1,000+
GUPPY	1,000
OPSUB	1,000
MERMAID II	1,000
DIAPHUS	1,200
PC-14C-2	1,200
PC-17	1,500
BEAVER MARK IV	2,700
DEEP QUEST	8,000
ALVIN	12,000

The 5 U.S. Navy owned manned vehicles operated by the U.S.N. SUBMARINE DEVELOPMENT GROUP ONE are:

DSRV-1	5,000
DSRV-2	5,000
SEA CLIFF	6,500
TURTLE	6,500
TRIESTE II	20,000

For reference purposes, illustrations of these submersibles are included, with the exception of PC-17, which is under construction.

*NOTE: Appendix A has been added to this report, but was not included in the InterOcean 76 paper.

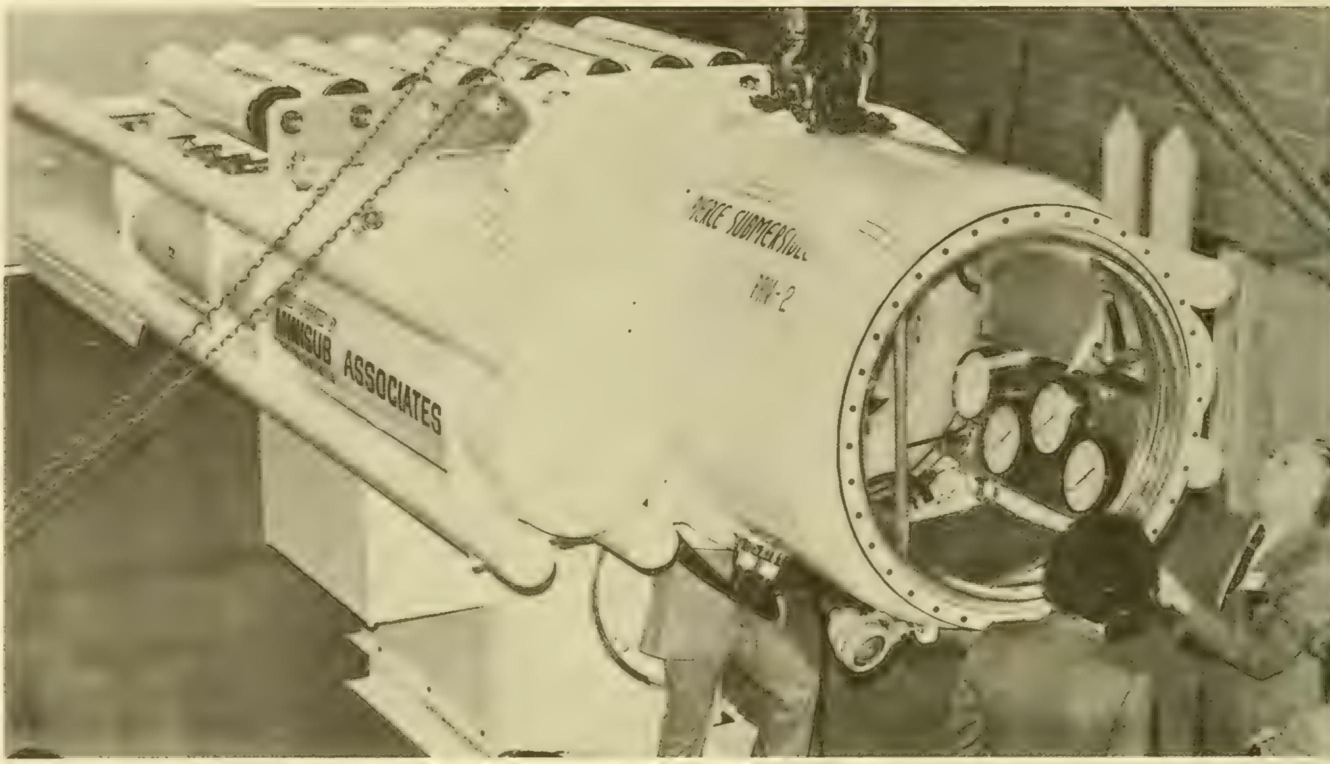

FIGURE 23. PRV-2 - PIERCE SUBMERSIBLES

FIGURE 24. NEKTON BETA - GENERAL OCEANOGRAPHICS

FIGURE 25. NEKTON GAMMA - GENERAL OCEANOGRAPHICS

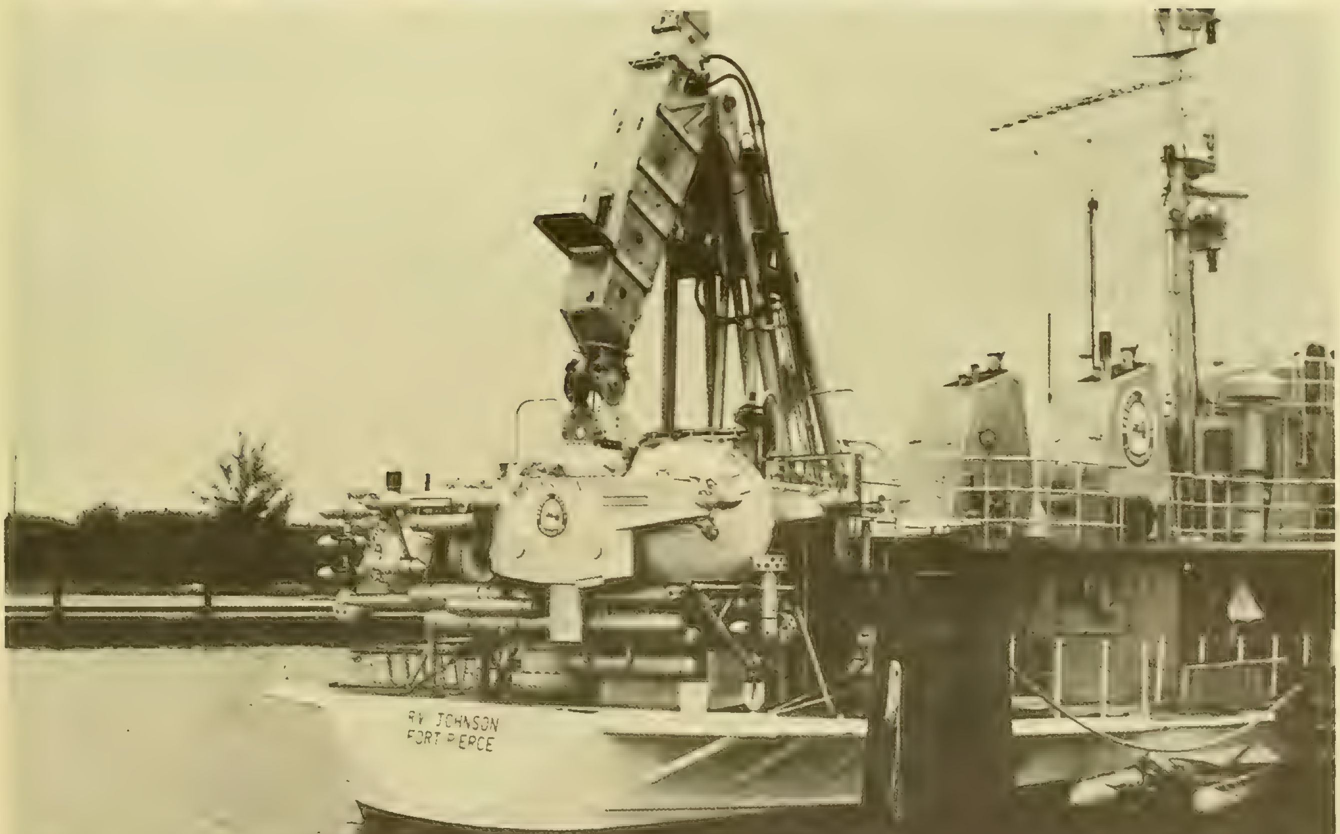

FIGURE 26. JOHNSON SEA LINK I - HARBOR BRANCH FOUNDATION
(Note: Johnson Sea Link II is identical in appearance)

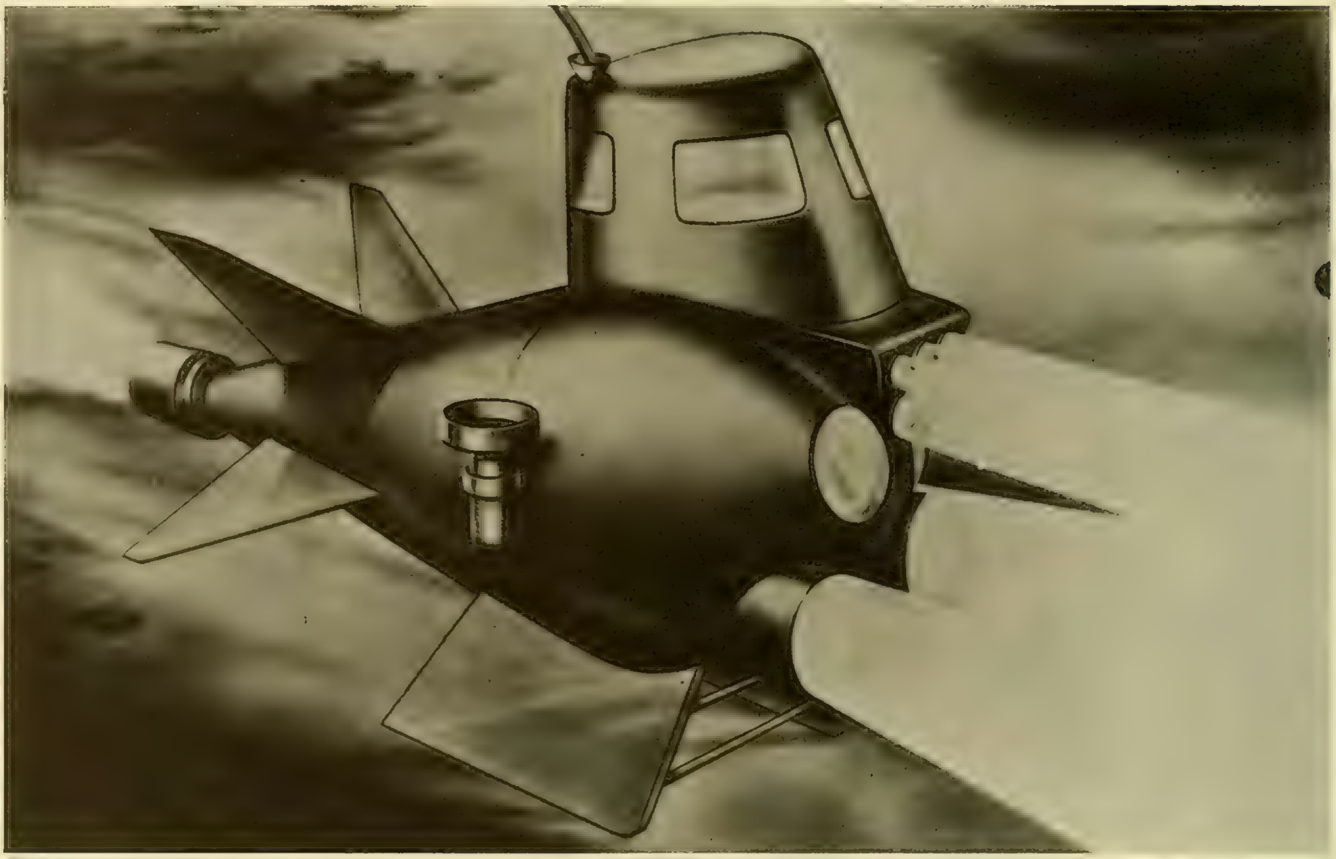

FIGURE 27. GUPPY - SUN SHIPBUILDING & DRYDOCK CO.

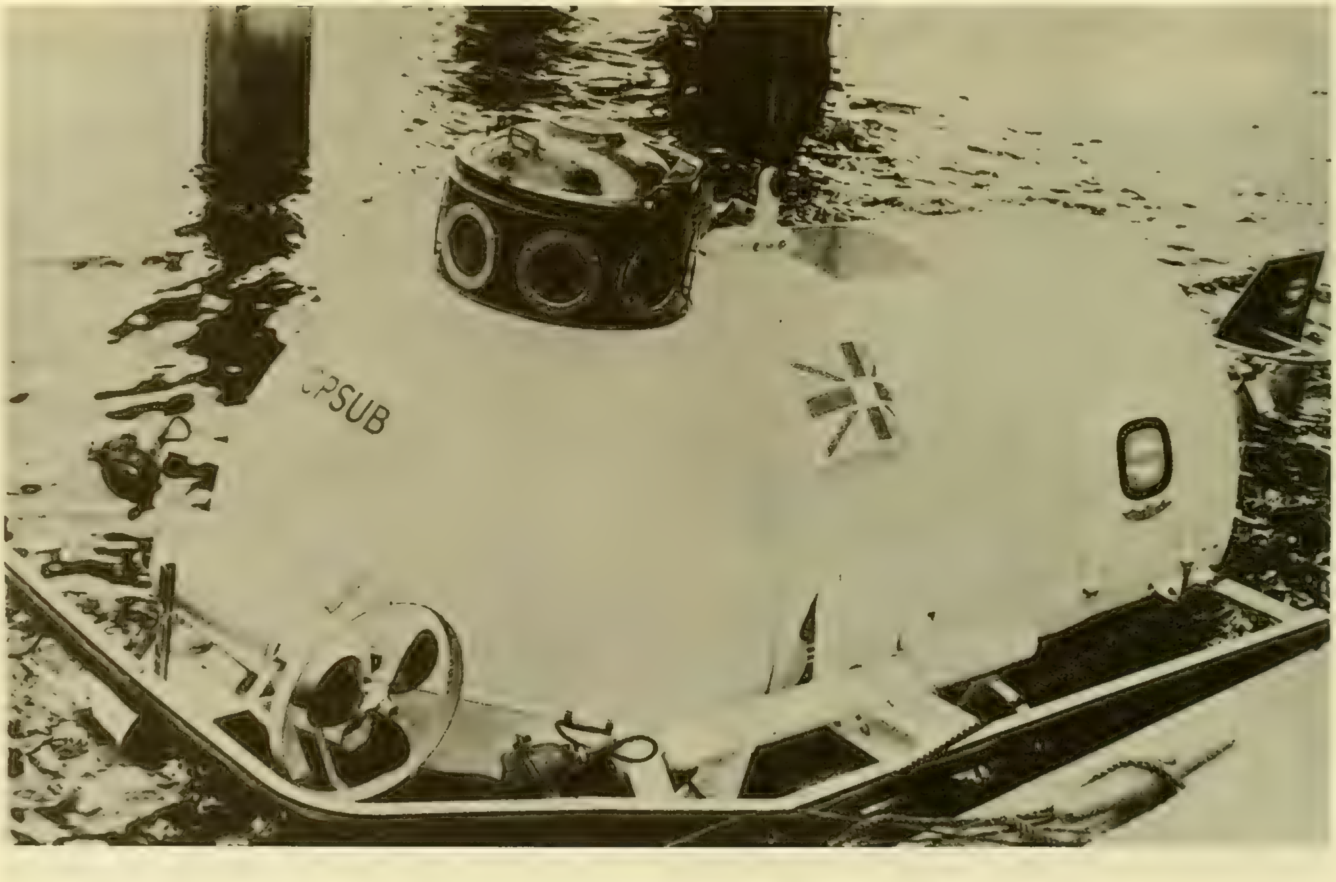

FIGURE 28. OPSUB - OCEAN SYSTEMS

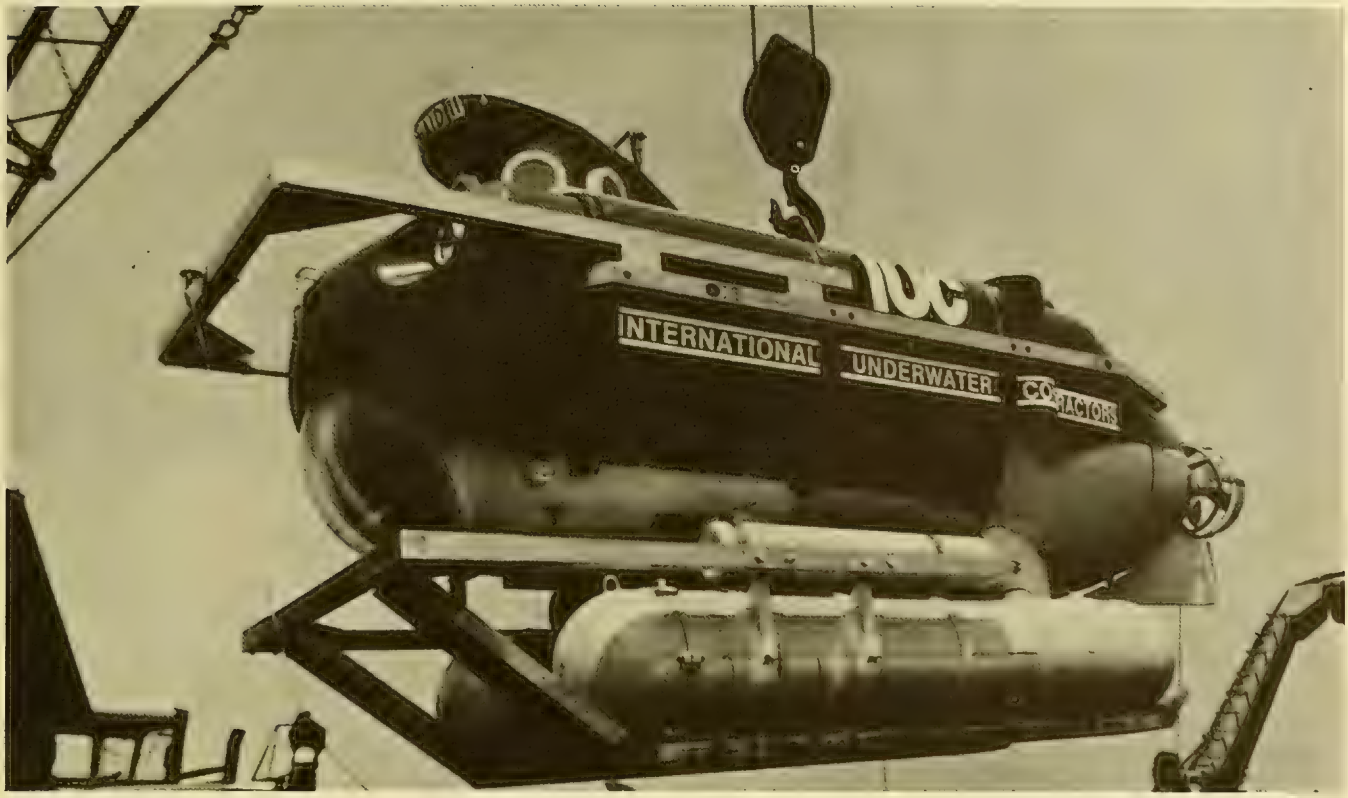

FIGURE 29. MERMAID II - INTERNATIONAL UNDERWATER CONTRACTORS INC.

FIGURE 30. DIAPHUS - TEXAS A&M UNIVERSITY

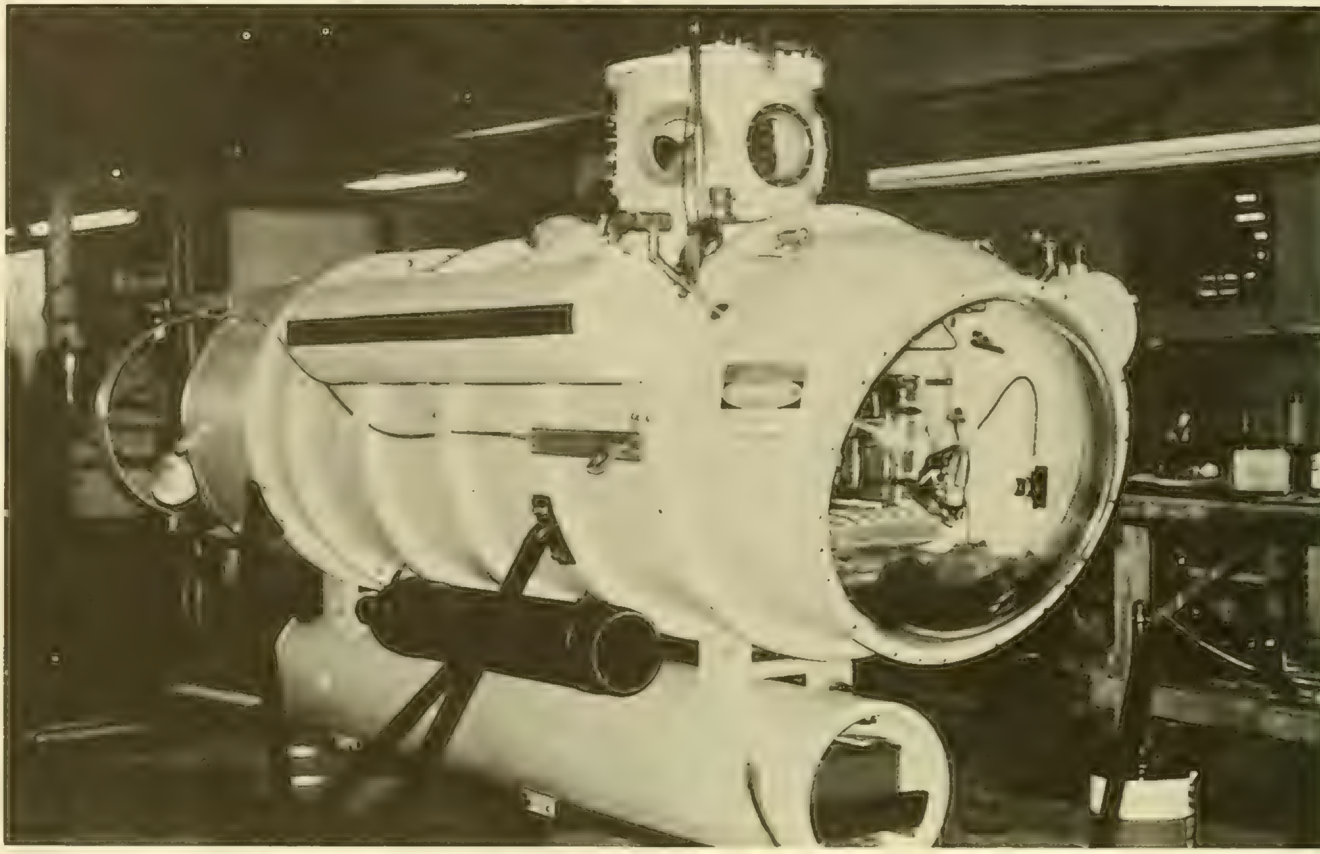

FIGURE 31. PC-14C-2 - U.S. ARMY BALLISTIC MISSILE COMMAND

FIGURE 32. BEAVER MARK IV - INTERNATIONAL UNDERWATER CONTRACTORS INC.

FIGURE 33. DEEPQUEST - LOCKHEED CORPORATION

FIGURE 34. ALVIN - WOODS HOLE OCEANOGRAPHIC INSTITUTE

FIGURE 35. DSRV-1 - U.S. NAVY
(Note: DSRV-2 is similar in appearance)

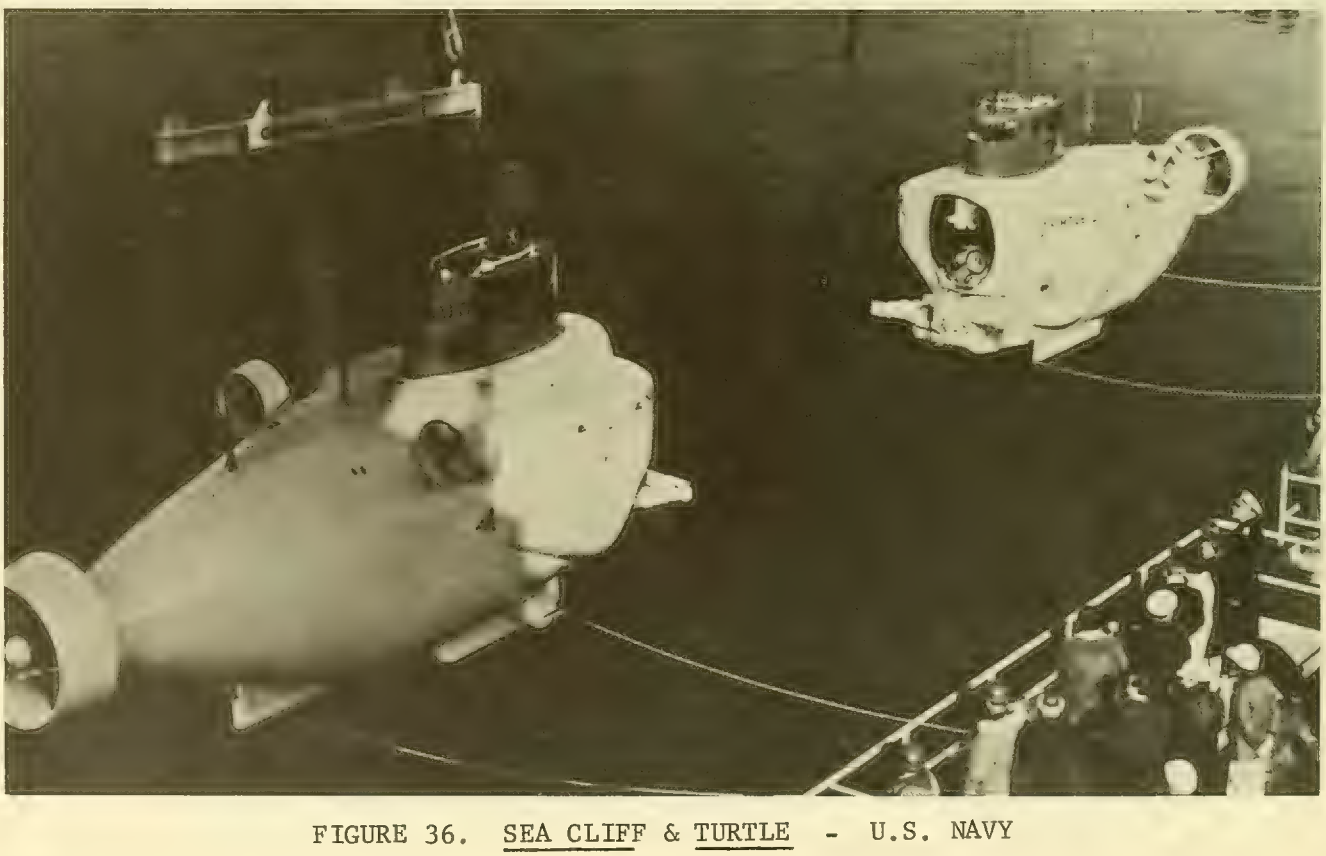

FIGURE 36. SEA CLIFF & TURTLE - U.S. NAVY

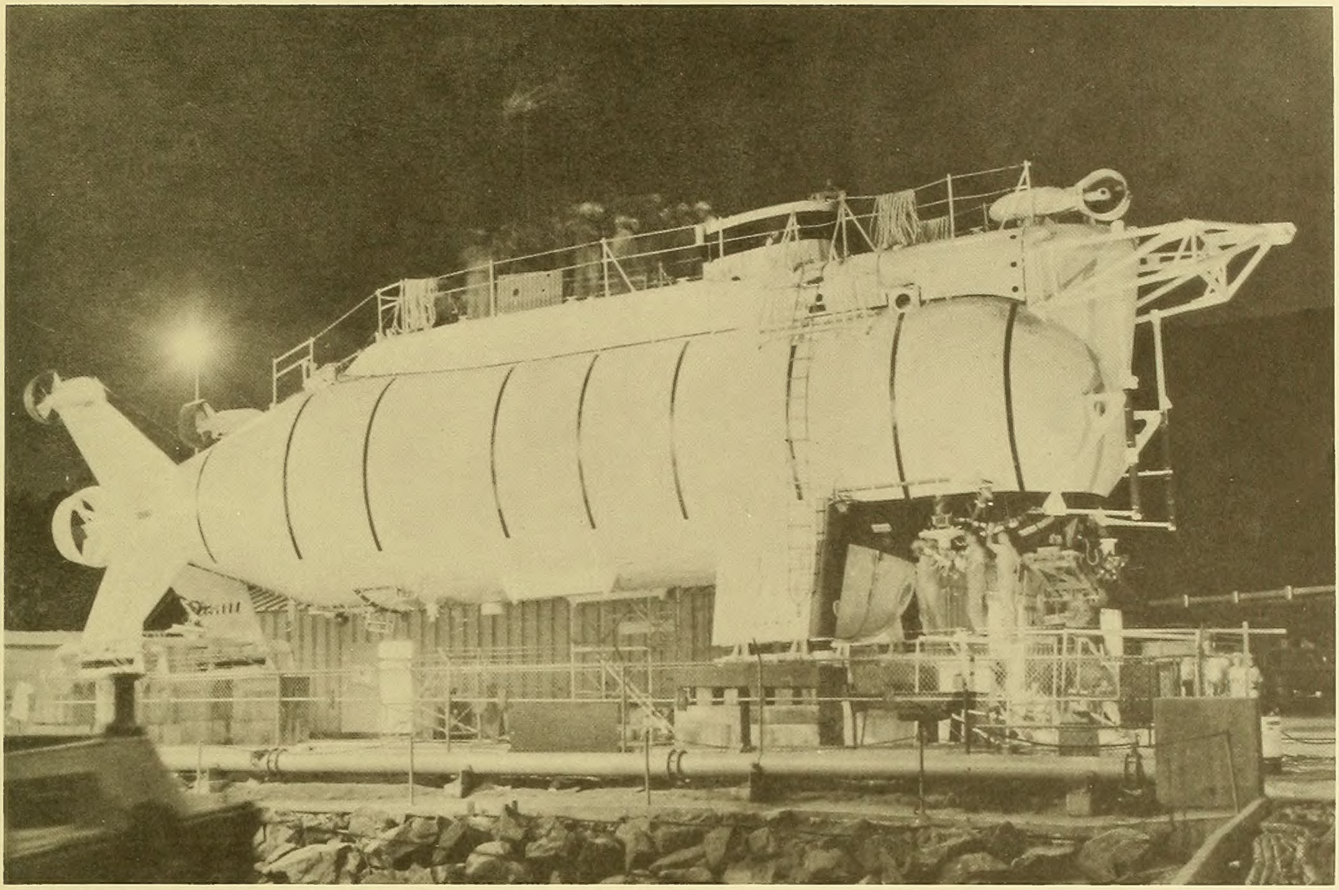

FIGURE 37. TRIESTE II - U.S. NAVY